

# PRODUCTION AND PROPERTIES OF SPRAY-DRIED WHOLE MILK FOAM

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## SUMMARY

Droplets of concentrated whole milk foam have been dried in a standard spray dryer. This has been done by incorporating nitrogen gas into the concentrate at high pressure prior to atomization. The resultant powder has excellent dispersibility properties and can be produced at rates in excess of those obtained by conventional operation. The method of foam-spray drying employed and the physical properties of the resultant powders are given in detail.

The dehydration of milk to a flavor-stable, easily reconstitutable powder is so obviously desirable that history extending back 500 yr records efforts to dry milk (3). In spite of repeated failures to obtain that ultimate product, a highly soluble powder reconstituting to a beverage virtually indistinguishable from fresh pasteurized milk, research has persisted in striving towards this goal. Progress has been made to the extent that at the present time approximately two billion pounds of milk powder are produced annually in the United States (8).

The bulk of this material is in the nonfat form, since dry whole milk produced by either roller or spray drying is difficult to disperse and has poor storage stability. Experiments reported in 1957 by Sinnamon et al. (5) indicated that drying foams of concentrated milk under high vacuum would produce a whole milk powder of excellent initial flavor and dispersibility. Morgan and his associates (4) demonstrated that this dispersibility could be maintained in foamed products even during drying at atmospheric pressure. Work carried out in our Laboratories has suggested that the unique feature of vacuum foam-dried milk, possibly contributing greatest to its high dispersibility, was the low density structure of the powder particles which allowed water uptake at rates which prevented destabilization of the protein systems during rehydration. To test this idea, and possibly produce an easily dispersible whole milk powder by modifications of a standard commercial drying technique, attempts were made to dry droplets of foamed milk concen-

trates in a conventional spray dryer. This paper describes the technique employed and some of the physical properties of the resultant powder.

## EXPERIMENTAL PROCEDURES

All powders were made from milk obtained from a herd maintained under invariant husbandry at the Agricultural Research Center, Beltsville, Maryland. Milk was collected in bulk tanks over a three-day period before drying.

The milk was standardized to 3.3% fat, heated to 165 F for 15 sec in a Mallory heater,<sup>1</sup> homogenized at 2,500 lb and concentrated to 50% solids in a Wiegand<sup>1</sup> falling film evaporator of 100-gal-per-hour capacity.

The concentrate, held at 90 F, was dried using a modified 9-ft Swensen spray dryer<sup>1</sup> equipped with a pressure nozzle designed and manufactured by the Whiting Corporation.<sup>1</sup> The modification consisted of providing a means for injecting nitrogen gas under pressure into the feed line between pump and nozzle. This was accomplished by use of a stainless steel, modified T joint built as illustrated in Figure 1. This mixing device placed approximately 1½ ft from the outlet of a 100-gal/hr positive displacement pump, was supplied with nitrogen from standard pressure tanks. The nitrogen pressure was reduced to and held at 2,000 lb by a Victor regulator.<sup>1</sup> Rate of flow of nitrogen into the mixing device was determined by use of a Brooke's high-pressure flow meter<sup>1</sup>

<sup>1</sup> The use of trade names is for the purpose of identification only, and does not imply endorsement of the product or its manufacturer by the U. S. Department of Agriculture.

and manually controlled by a needle valve in the line after the flow meter. The positive displacement pump was equipped with a spring-loaded by-pass valve which allowed the utilization of various nitrogen/concentrate ratios while maintaining a constant pressure of 1,800 lb on the spray head. The amount of concentrate dried per unit time was determined by subtracting the by-pass rate from the rating of the pump.

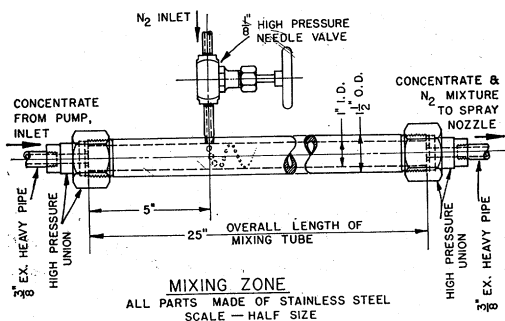


FIG. 1. Mixing device used for incorporation of nitrogen into milk concentrate prior to atomization.

Experimental powders were made by drying various nitrogen/concentrate mixtures using nozzles with orifice sizes ranging from .040 to .050 inch in diameter. A constant air inlet rate with an air temperature of 270 F was employed in all drying runs.

The moisture content of the resultant powders was determined by using the conventional toluene distillation technique. Bulk density was determined by measuring the volume occupied by a lightly tapped 10-g sample. Free fat and dispersibility in 34 F water were measured as previously described (7). Diameters of individual particles and clumps were measured using a microscope equipped with a calibrated eyepiece scale and above-stage lighting. Particle size distribution was ascertained by microscopic examination of random fields. Specific surface areas of the powder were determined using an adaptation of a standard permeametric method (1), which will be the subject of a later publication.

#### RESULTS

The blending of nitrogen gas and concentrated whole milk under pressure just before atomization in a conventional spray dryer produces material characterized by increased bulk and improved dispersibility. Viewed under a microscope the particles appear to be relatively

large spheres of dried milk foam, as shown in Figure 2. During drying a considerable number of the spheres coalesce and fuse into aggregates. The individual spheres and aggregates do not break or crush on handling and packaging. A distribution of particle sizes in conventional spray dried and foamed spray-dried powders is shown in Figure 3. Large aggregates found in the conventional material were due to clumping caused by the high moisture content of the powder.

The effects of incorporating increasing amounts of nitrogen in the concentrate before atomization on dryer operation and powder characteristics are tabulated in Table 1. From this it can be seen that as the amount of nitrogen in the feed is increased, the amount of concentrate being dried decreases along with the bulk density and moisture contents of the resultant powders. Increasing amounts of nitrogen in the concentrate increases the dispersibility, free fat, and particle diameters.

The increase in dispersibility is most marked between samples produced using zero levels of nitrogen and those produced by lowest level of nitrogen incorporation. Even though results from measuring the dispersibility of foamed samples are erratic, averages of all products produced by different-sized nozzles at each nitrogen injection level indicate an increase in dispersibility with increased  $N_2$  incorporation. At constant atomization pressure, increasing the diameter of the nozzle orifice necessarily increases the amount of material being dried. A serious loss in the ability of the dryer to produce acceptably dried powder as nozzles of increasing orifice size are used is noted if nitrogen is not incorporated into the concentrate. This increase in moisture content of the powder with increasing nozzle orifice diameter is not so marked when nitrogen is blended into the dried feed. The increased efficiency of drying effected by the use of added nitrogen actually allows the dryer to successfully produce milk powder in quantities in excess of its rated capacity for conventional spray drying. Adequate demonstration of this can be obtained from comparisons of data in Columns 2 and 4 of Table 1. From the data therein, it can be seen that without gas incorporation none of the powders was dried to, or below, the acceptable 3.5% moisture level. Using the smallest nozzle, 669 lb of concentrate could be reduced to 3.6% moisture in 1 hr. By use of nitrogen incorporation, 793 lb of concentrate could be reduced to 3.2% moisture in a similar period of time. Part of this improved dryer performance may result from the increased buoyancy

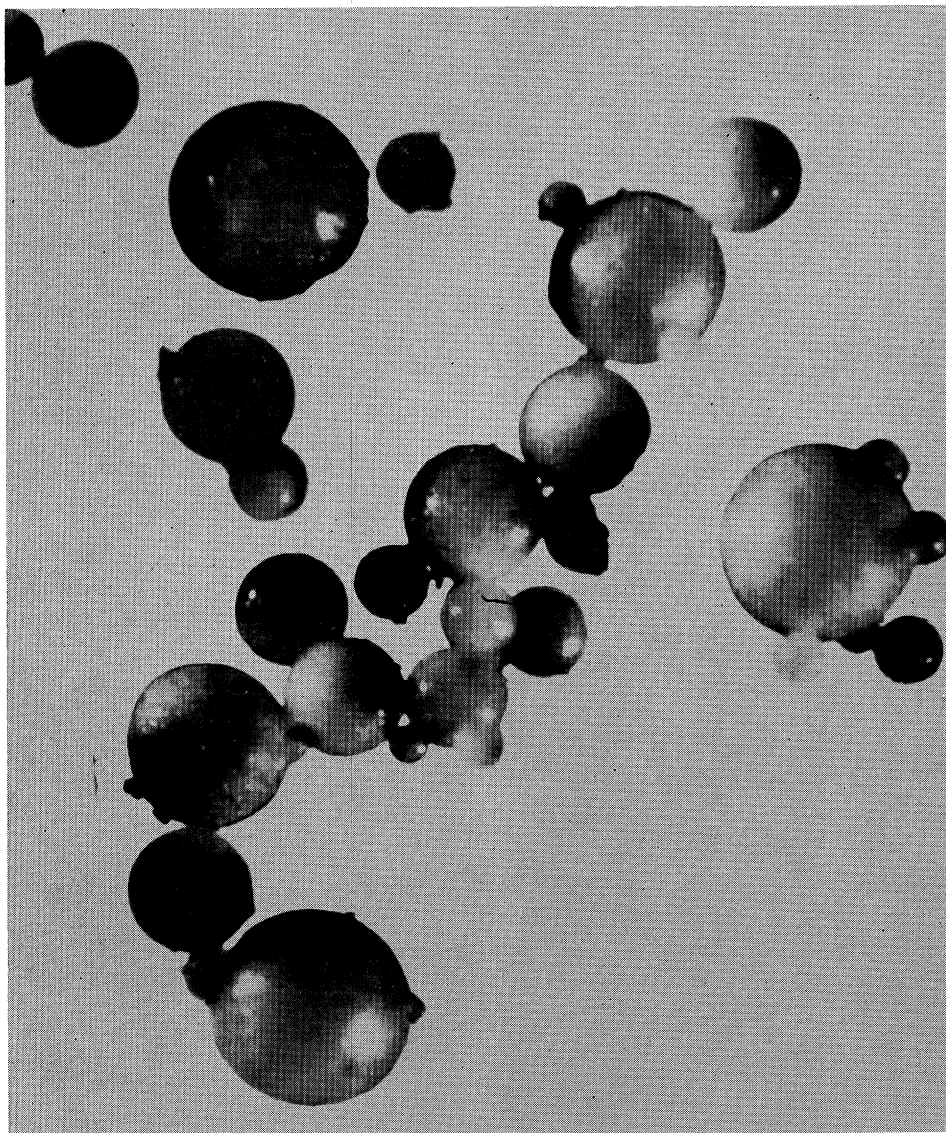


FIG. 2. Photomicrograph of foam-spray dried milk powder particles (285 $\times$ ).

of the foamed particles, which may slightly increase the time they remain in the dryer.

Since at least part of the increased particle size is brought about by the expansion of gas trapped in the spheres of milk foam formed during atomization, an increase in the specific surface areas of the powders should accompany the increased nitrogen content of the feed material.

Figure 4 graphically presents the relationships between surface area, nozzle orifice diameter, rate of nitrogen flow into the drier feed, and feed rate. From this it can be seen that

the greatest increase in specific surface area with increasing nitrogen content is obtained using the smallest nozzle opening. The amount of surface expansion per unit nitrogen flowing into the concentrate falls off as the amount of nitrogen increases.

#### DISCUSSION

Even though the drying technique described in this paper necessitates the use of a gas under pressure, this inconvenience and cost may be compensated by improved dryer efficiency. This observed increase in drying rate with nitrogen

incorporation stems from the increased surface areas available for mass and heat transfer in the foamed particles. Resistance to diffusion of water vapor to the surface of the powder particles is also reduced by decreasing the density of the powder particles by bubble production.

Microscopic examination of powder particles suspended in glycerol reveals two types of bubbles in the particles. One type, extremely small and profuse, is located throughout the milk solids; the other, relatively large and fewer in number, occupies the interiors of the particles and the spherical protuberances on their surfaces.

It is reasonable that these two types of bubbles arise, respectively, from the dissolved gas and that dispersed in the liquid concentrate by the extreme turbulence in the mixing device and in the line to the atomizer. The pressure drop and temperature increase experienced on atomization may cause the dissolved gas to be released to form a fine-grained foam, trapping the larger bubbles of gas and some of the water vapor evolved during drying.

Some of the increase in particle size observed in powders produced by gas incorporation certainly results from the expansion of

the trapped nitrogen gas. However, by use of a micro-balance and microscopic dimension measurements, it was found that the individual powder particles had densities varying between .5 and .6 g/cc, which is much higher than would be anticipated from a simple expansion of a standard-sized spray droplet by trapped gas. Therefore, the increased numbers of large-sized particles observed in the foam-spray dried

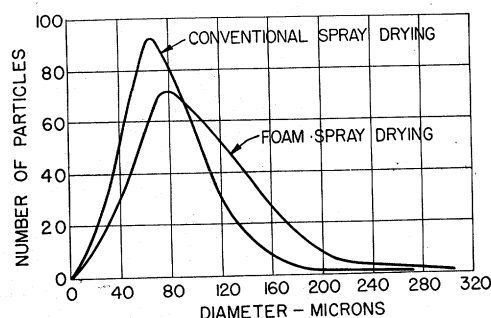


FIG. 3. Particle size distribution in spray-dried powders produced with and without gas incorporation. Both samples produced by spraying through .048-inch nozzle orifice. Foamed product made by introducing .15 standard cubic feet of  $N_2$  into each pound of 50% concentrate before atomizing. Moisture content of powders: without gas, 4.9%; with gas, 3.2%.

TABLE 1  
Physical properties of whole milk powder produced by incorporating pressurized gas into the concentrate prior to drying

Drying conditions		Physical properties of milk powder						
Nozzle orifice diameter	Dryer feed rate	Nitrogen injection rate	Residual moisture	Bulk density	Free fat	Dispersibility	Average individual sphere diameter	Average clump size
(inches)	(lb 50% conc./hr)	(SCFN <sub>2</sub> /lb <sup>a</sup> conc)	(%)	(g/cc)	(%)	(%)	(μ)	
.040	538	.45	2.3	.21	25.1	85.5	94.86	147.56
.040	581	.21	2.5	.23	20.7	91.9	92.82	196.52
.040	634	.14	3.5	.30	8.0	89.2	84.32	195.84
.040	669	0	3.6	.53	2.8	69.8	68.34	280.50
.0465	709	.34	2.2	.24	19.5	93.0	104.04	269.62
.0465	739	.16	3.1	.26	13.2	80.8	96.56	153.00
.0465	779	.12	3.8	.32	7.0	85.5	92.14	250.24
.0465	802	0	4.5	.50	3.2	66.9	78.54	429.08
.048	743	.32	2.2	.24	18.2	93.8	93.84	140.76
.048	780	.15	3.2	.25	13.9	92.8	103.36	216.24
.048	811	.11	4.0	.32	7.9	86.2	87.04	259.08
.048	835	0	4.9	.45	4.3	55.3	62.90	330.14
.050	759	.31	2.6	.23	17.9	89.6	100.98	156.40
.050	793	.15	3.2	.25	11.7	88.5	93.84	200.60
.050	831	.10	4.0	.29	7.1	89.4	90.10	287.30
.050	855	0	5.6	.48	3.5	71.8	74.12	305.32

<sup>a</sup> Standard cubic feet  $N_2$ /lb 50% concentrate.

product must be due, in part, to a change in the atomization characteristics of the nozzle.

On reconstitution, the gas trapped in the interior of the spray-dried foams is released and rises to the surface to form a fine-grained froth. The persistence of this material has interfered with the dispersibility test used in this study. Even though the results are somewhat erratic, the improved dispersibility of the spray-dried whole milk foam powders is clearly demonstrated. These data tend to give some credence to the idea that, in whole milk powders, high bulk density with good dispersibility is not obtainable through manipulation of the drying technique alone.

The idea of changing the physical properties of a spray-dried powder by incorporating gas into the feed material is certainly not unique. A patent issued in 1957 to Standard Brands (6) describes the spray drying of foamed coffee extracts. The application of this principle to milk drying has undoubtedly been attempted in a number of laboratories. However, the methods and results of these experiments have never been published.

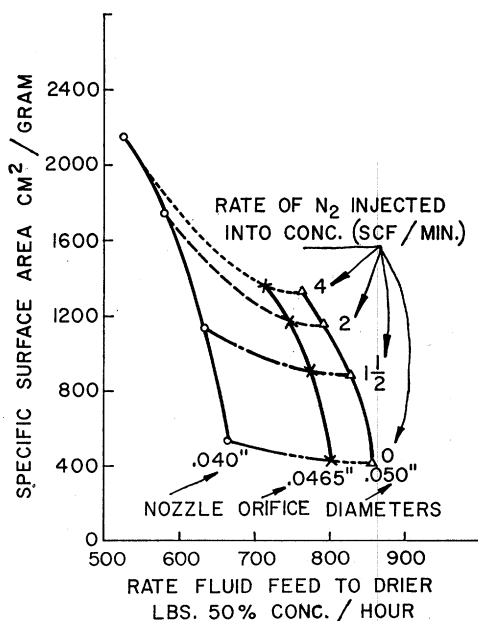


FIG. 4. Relationships between some factors influencing specific surface area of spray-dried whole milk powder.

The technique of producing spray-dried foams as presented in this paper is relatively simple, easy to control, and can possibly be carried out in most existing driers with only minor modifications. The increased drying efficiency observed during the development of this technique has already been utilized to dry Cottage cheese whey (2). From preliminary work with other food products, it can be stated that this drying method will be most applicable to materials possessing high-foaming capacity and foam stability.

Studies of the stability of dried whole milks produced by this method are under way at present.

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